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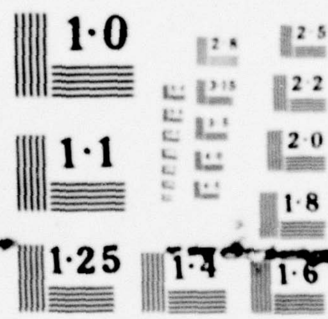
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FINAL REPORT

WORKSHOP ON IMAGE MODELLING

August 6-7, 1979
Hyatt Regency O'Hare
Chicago, IL 60666

Sponsored by

National Science Foundation
Washington, DC 20550
Grant MCS-79-04414

and

Office of Naval Research
Arlington, VA 22217
P.O. N00014-79-M-0070

to

Computer Science Center
University of Maryland
College Park, MD 20742

Principal Investigator:
Azriel Rosenfeld

August 31, 1979

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Preface

It has long been recognized in the field of image processing that the design of processing operations should be based on a model for the ensemble of images to be processed. This realization is becoming increasingly prevalent in the field of image analysis as well. Unfortunately, it is difficult to formulate realistic models for real-world classes of images; but progress is being made on a number of fronts, including models based on Markov processes, random fields, random mosaics, and stochastic grammars, among others. At the same time, analogous models are being developed in fields outside image processing, including stereology, mathematical morphology, integral geometry, statistical ecology, and theoretical geography.

This Workshop was devoted to a review of the major ideas on image modelling that have been developed in the fields of image processing and analysis, as well as related ideas that have been developed in other fields. The presentations at the Workshop emphasized general aspects, rather than problem-domain-dependent considerations. Thus the Workshop served to focus attention on the field of image modelling by providing a review of possible approaches. It also served to stimulate contact between the researchers in image processing, statistics, and other disciplines who participated in it.

It is planned to publish the Workshop Proceedings in book form (Academic Press, 1980). For this reason, the present report provides only a brief summary, including the Workshop program, abstracts of papers, and lists of invited participants and attendees.

WORKSHOP ON IMAGE MODELING

International Ballroom
Hyatt Regency O'Hare, Chicago, IL

Program

Monday, August 6

8:45 AM - 12:30 PM

A. Rosenfeld, Introduction

C. A. Harlow and R. W. Conners, The theoretical development of a texture algorithm based on statistical models of texture

M. Hassner and J. Sklansky, The use of Markov random fields as models of texture

T. S. Huang, Mathematical models of graphics

L. N. Kanal, The Markov mesh model

R. L. Kashyap, Multivariate autoregressive processes for images

J. T. Tou, Pictorial feature extraction and recognition via image modeling

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J. P. Serra, The Boolean model and its derivatives

G. T. Herman, On the noise in images produced by computed tomography

B. R. Hunt, Nonstationary statistical image models

W. K. Pratt and O. D. Faugeras, A stochastic texture field model

B. Schachter, Long-crested wave models

W. R. Tobler, Generalization of image processing and modeling concepts to polygonal geographical data sets

S. W. Zucker and D. Terzopoulos, Finding structure in co-occurrence matrices for texture analysis

<u>Tuesday, August 7</u>

<u>8:45 AM - 12:30 PM</u>

R. E. Miles, A survey of geometrical probability in the plane

N. Ahuja, Mosaic models for images

L. S. Davis, Detecting edges in textures

B. R. Frieden, Statistical models for the image restoration problem

R. M. Haralick, A facet model for image data

J. W. Modestino, R. W. Fries, and A. L. Vickers, Stochastic image models generated by random tessellations in the plane

T. Pavlidis and P. C. Chen, Image segmentation as an estimation problem

<u>2 - 5:45 PM</u>

D. E. McClure, Image models in pattern theory

D. B. Cooper, Stochastic boundary estimation and object recognition

H. Freeman, Comparative analysis of line-drawing modelling schemes

K. S. Fu, Syntactic image modelling using stochastic tree grammars

B. Julesz, Differences between attentive (figure) and preattentive (ground) perception

J. M. Tenenbaum and H. G. Barrow, Intrinsic surface characteristics: a physically motivated alternative to image modeling

H. Chernoff, Concluding remarks

WORKSHOP ON IMAGE MODELING

August 6-7, 1979

Chicago, IL

ABSTRACTS OF PAPERS

"The Theoretical Development of a Texture Algorithm Based on Statistical Models of Texture." Charles A. Harlow and Richard W. Conners, Department of Electrical Engineering, Louisiana State University, Baton Rouge, LA 70803.

The theoretical development of a texture algorithm is discussed. The development work done thus far includes the theoretical evaluation of four texture algorithms to perform texture discrimination.

The algorithms examined are the Spatial Gray Level Dependence Method, the Gray Level Run Length Method, the Gray Level Difference Method and the Power Spectral Method. The evaluation procedure employed does not depend on the set of features used with each algorithm or the pattern recognition scheme. Rather, what is examined is the amount of texture-context information

contained in the spatial gray level dependence matrices, the gray level run length matrices, the gray level difference density functions and the power spectrum. To do this type of evaluation a number of mathematical formulations are required. To make these formulations mathematically tenable, the class of textures considered is limited to Markov generated textures. The Markov textures employed are similar to the ones used by Julesz in his investigations of human texture perception. The algorithm which was found to be the most robust was the Spatial Gray Level Dependence Method.

The second part of the development work which is described details the efforts made to find a set of features to measure on the spatial gray level dependence matrices. The features are envisioned as being the primitive operators which will be used by a hierarchical structural level to make inferences about the basic underlying fabric of the texture. Proceeding in this fashion allows one to combine the best features of both the statistical level and structural level of texture discrimination.

In particular, a methodology will be discussed which will allow the Spatial Gray Level Dependence Method to be used to detect boundaries of textured regions and to determine the unit cell size of a textural pattern. The unit cell is the fundamental building block of a texture. It is the tile which can be used to cover the plane and create an image of the texture. This concept is similar to one described by Zucker. The development and analysis of the texture edge detector and unit cell size measure also uses statistical models for texture.

"The Use of Markov Random Fields as Models of Texture."
Martin Hassner and Jack Sklansky, School of Engineering,
University of California, Irvine, CA 92717.

The objective of this paper is to introduce Markov random fields, and in particular, their Gibbs parametric description, as a unified and useful framework for the modelling of digital image texture. We demonstrate the equivalence of the Gibbs parameters to the Markov model by analysis of the graph structure of the digital image space. The Gibbs-Markov equivalence is the correspondence between (a) a collection of local conditional probabilities defined on a spatial neighborhood and (b) a collection of real valued parameters defined on the collection of connected subgraphs of the spatial neighborhood connectivity graph. These subgraphs or "cliques" are the ingredients of an efficient representation of digitized texture.

Both discrete and continuous valued Markov random fields can be represented by Gibbs parameters. We present algorithms for optimally estimating the Gibbs parameters of both discrete and continuous valued textures. (We assume that the continuous valued textures can be represented by Gaussian Markov random fields.) The existence and properties of these optimal estimates and the algorithms for their computation are a direct consequence of the identification of Markov random fields as a subclass of exponential models. The latter are widely used in the analysis of multivariate data because of the existence of a sufficient statistic for the model parameters. In a digital texture this sufficient statistic is the histogram of cliques. (For a given value of this sufficient statistic, the maximum likelihood parameter estimates coincide with the maximum entropy estimates.) The fundamental idea of our estimation algorithm is the moment matching method. By this method the observed moments and the moments derived from the model are constrained to be equal. The optimal parameter estimate achieves this equality.

Markov random fields in which the dependence among neighboring pixels is unidirectional are known as unilateral (causal) Markov random fields. Markov random fields without such a unidirectional dependence are multilateral. The estimation of the Gibbs parameters of multilateral Markov random fields requires an iterative ascent on a likelihood function, whereas closed form estimates exist for unilateral Markov random fields.

We define the pressure function of the Gibbs parameters as an information theoretic measure of texture complexity. This leads to the concept of relative pressure as a measure of the goodness of fit of a Markov random field to real data. The mathematical and computational properties of the pressure function are strikingly similar to those of the rate distortion function used in communication theory. We present algorithms for the computation of the pressure function.

Due to the Gibbs-Markov equivalence, the Gibbs parameters can be used to simulate Markov random field digital textures. Multilateral Markov random fields are simulated by Monte Carlo methods through their imbedding in a spatial temporal process that evolves according to a relaxation equation until an equilibrium state is reached. This equilibrium state is the Markov random field specified by the Gibbs parameters. We present a fast Monte Carlo algorithm that performs this simulation efficiently. Another class of algorithms is introduced for the simulation of unilateral Markov random fields that can be generated recursively. These algorithms have an advantage since they generate textures element by element for a specified boundary rather than going through the image by image iterations of the Monte Carlo method.

We introduce a simulation algorithm that is based on a vector Markov chain construction which results in unilateral discrete or Gaussian random fields. These textures possess a

separable exponential correlation structure. Experiments at Bell Laboratories suggest that most real pictures possess such a correlation structure. This correlation structure of a unilateral Markov random field implies the existence of a Markov chain along each of its monotonic paths.

Markov random fields are useful models for the development of automatic texture classifiers, because (a) these fields can be simulated effectively and (b) the correlation structures of second order properties of these fields specify a family of textures that can be discriminated on the basis of their Gibbs parameters.

We describe a proposed method of classifying textures based on their Gibbs parameters. We define the divergence and Bh-distance in terms of these parameters. We show that the probability of error or misclassification of a classifier can be bounded in terms of these distances.

"Mathematical Models of Graphics." Thomas S. Huang, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907.

We concern ourselves with the efficient coding of graphics (i.e., images which have only two gray levels) for transmission or storage. Four categories of mathematical models for graphics as data sources are presented as well as the interplay between these models and coding schemes: Joint probability models, conditional probability models, contour models, and pattern recognition models.

The word "graphics" is used to mean images which are either strictly or nominally binary. Thus, graphics include the following three classes of images:

1) Images which are nominally two-tone. Examples are business documents (especially typewritten letters), weather maps, engineering drawings, newspaper and magazine pages, fingerprint cards.

2) Binary images derived from continuous-tone images.

   (a) To represent a continuous-tone image in digital form requires 5-8 bits per picture element (pel). We can transmit or store this multi-bit image in terms of its bit planes. Each bit plane is a strictly binary image.

   (b) Sometimes we cannot afford to transmit or store a multi-bit image. Then we might want to get a binary approximation of the continous-tone image and work with that. E.g., one possibility is to use the dynamic thresholding technique of Morrin to reduce a continuous-tone image to a binary one.

3) Binary images created in some continuous-tone image coding schemes.

   (a) In some transform coding schemes, one needs to transmit or store the locations of selected transform

coefficients in each block. The locations can be represented by a binary image.

(b) In contour coding schemes, the contour information forms a binary image.

In this paper, we shall concentrate on the first image class, especially business documents and weather maps. The transmission and storage of business documents is of particular concern because of its potential commercial market.

"The Markov Mesh Model." Laveen N. Kanal, Laboratory for Pattern Analysis, Department of Computer Science, University of Maryland, College Park, MD 20742.

The Markov Mesh Model for modeling certain types of spatial dependencies in images was introduced by the author and his colleagues. This paper briefly presents the basic idea and considers the model in the light of other two-dimensional Markov models for image representation.

"Multivariate Autoregressive Processes for Images." R. L. Kashyap, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907.

Images can be described either by multivariate autoregressive processes or multidimensional autoregressive processes. In this paper, we will discuss the choice of multivariate models for images. We will develop a minimum error Bayes decision rule for choosing the best model for the given image. We will also discuss the advantages of the multivariate model over the multidimensional model.

"Stochastic Processes for Describing Image Boundaries." R. L. Kashyap, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907.

A boundary of an image or any closed curve without knots can be shown to be equivalent to a one-dimensional time series derived from the boundary or curve. The time series can be represented by a variety of stochastic processes such as unilateral autoregressive processes, bilateral autoregressive processes, seasonal autoregressors, Fourier series models, etc. Using a Bayesian approach, we show how to choose the appropriate type of stochastic process and the parameters of the stochastic process which will fit the given image boundaries. We also indicate how the fitted model can be used in classification problems.

"Pictorial Feature Extraction and Recognition via Image Modelling." Julius T. Tou, Center for Information Research, University of Florida, Gainesville, FL 32611.

This paper presents some approaches to image modelling for pictorial feature extraction and recognition which we have developed during the past several years. One of the major problems in automated pictorial pattern recognition is to reduce textural image information for machine implementation and interpretation. In an attempt to solve this problem, we have taken two approaches: the statistical approach and the structural approach. Under the statistical approach, we introduced a two-dimensional statistical model which is expressed in the form of a recursive algorithm in terms of data points and white noise. Under the structural approach, we characterized a textural image by the eigenvalues and eigenvectors of its gradient distribution matrix, and we also developed the pixel vector approach to modelling textural images. In this paper, we make an expository presentation of some of the theories of image modelling which we have developed.

"The Boolean Model and Its Derivatives." Jean Serra,
Centre de Morphologie Mathématique, 35 rue Saint-Honoré, 77305, Fontainebleau, France.

We propose to present the main theorems which govern random set theory by studying one particular random set, namely the Boolean model. After defining the Boolean model X (union of almost surely compact random sets centered at Poisson points in $R^{(n)}$, the probability Q(B) that a given compact set B misses X is calculated. Several laws are derived from Q(B) (covariance, law of the first contact, specific numbers, etc.). We then go back to the basic theoretical problems raised by such an approach:

--What are the morphological mappings which transform one random set into another?

--What pieces of information are sufficient to characterize a random set?

--What is the general expression for indefinitely divisible random sets? Answers are given using G. Matheron and G. Choquet's theorems.

In the last part of the paper we show how Boolean sets may be handled in view of constructing more sophisticated models (tessellations, n-phased sets, hierarchical sets, etc.). Examples are given.

"On the Noise in Images Produced by Computed Tomography."

Gabor T. Herman, Medical Image Processing Group, Department of Computer Science, State University of New York at Buffalo, Amherst, NY 14226

Radiation passing through the human body is attenuated. The nature of the structures the radiation has passed through is indicated by the total attenuation of the radiation between its source and its point of detection. Computed tomography is a recent invention which has revolutionized diagnostic radiology. Computers are used to calculate the attenuation at individual points inside the body from a collection of total attenuations along a large number of lines (this process is called reconstruction) and to display the internal structures of the body based on this information.

In this paper we discuss the nature of noise in image produced by computed tomography. Noise is taken in its most general sense: any deviation from the "true" image is considered noise. The physical sources of noise in computed tomography are considered and their effects on the images produced are illustrated. The mathematical relationship between noise in the data and noise in the reconstruction is given for a particularly popular reconstruction method. Techniques of noise suppression in computed tomography images are surveyed.

"Nonstationary Statistical Image Models." B. R. Hunt, Systems Engineering Department and Optical Sciences Center, University of Arizona, Tucson, AZ 85721.

Common statistical image models, e.g., those used in restoration and bandwidth compression, use the assumption of stationarity. Images of interest never possess statistical spatial stationarity, however, and a major effort is warranted in research to overcome the assumption of stationarity in a manner which is computationally tractable. This is the topic we consider in this paper. In particular, we consider the potential for methods which transform a nonstationary image into one with stationary properties, processing by stationary methods, and inverse transformation back to a nonstationary framework. Implicit in such a concept is the measurement and characterization of nonstationarity in an image. We give an example of one such model based upon a nonstationary mean and show its application.

"A Stochastic Texture Field Model." William K. Pratt, Compression Labs, Inc., Cupertino, CA 95014, and Olivier D. Faugeras, I.R.I.A., Le Chesnay, France.

A stochastic texture field model has been developed as an aid in formulating and evaluating texture feature extraction methods. The model consists of an independent random field that is spatially correlated by a spatial operator to produce a texture field possessing controlled statistics.

Visual perception experiments are presented that serve to define necessary and sufficient statistical texture descriptors. Texture feature extraction methods based on the stochastic model are introduced and evaluated.

"Long-Crested Wave Models." Bruce Schachter, General Electric Company, P. O. Box 2500, Daytona Beach, FL 32015.

This paper examines two long-crested wave models. First, a traditional model is reviewed. It is based upon sums of a large number of sinusoids. It has found applications in oceanography, geology, and to some extent also in image analysis. Then, a new model is presented. It uses sums of three or fewer long-crested narrow band noise waveforms. It is designed specifically for the purpose of image analysis and synthesis. Results of experiments in the computer generation of textures are presented. This is the first texture model to be implemented in hardware in a real-time image generation system.

"Generalization of Image Processing and Modeling Concepts to Polygonal Geographical Data Sets." Waldo R. Tobler, Department of Geography, University of California, Santa Barbara, CA 96103.

The geographical distribution of phenomena (e.g., the incidence rate of heart disease or of cancer in the United States) can be considered to be a two-dimensional image, to which conventional image processing techniques may be applied. One of the difficulties of working in this area is that the data often come packaged in irregular spatial units (counties, census tracts, school districts, police precincts, etc.) with variable and spatially anisotropic, non-homogeneous, resolution. Examples of techniques for processing such images are demonstrated. A discussion is presented of approaches to problems of cross-spectral analysis applied to multiple geographical series assembled using different spatial aggregations, and to the deconvolution of such assemblages.

"Finding Structure in Co-occurrence Matrices for Texture Analysis." Steven W. Zucker and Demetri Terzopoulos, Computer Vision and Graphics Laboratory, Department of Electrical Engineering, McGill University, Montreal, Quebec, Canada.

Co-occurrence matrices are a popular representation for the texture in images. They contain a count of the number of times that a given feature (e.g., a given gray level) occurs in a particular spatial relation to another given feature. However, because of the large number of spatial relations that are possible within an image, heuristic or interactive techniques have usually been employed to select the relation to use for each problem. In this paper we present a statistical approach to finding those spatial (or other) relations that best capture the structure of textures when the co-occurrence matrix representation is used. These matrices should thus be well suited for discriminations that are structurally based.

"A Survey of Geometrical Probability in the Plane." Roger E. Miles, Australian National University, Canberra, A. C. T. 2600, Australia.

In this paper, I shall attempt to isolate key elements and themes of planar geometrical probability, both within a bounded region and over the whole plane, at a suitable level for "outsiders of mathematical maturity". Emphasis will be given to possible statistical models for planar phenomena of a random character.

"Mosaic Models for Texture." Narendra Ahuja, Computer Science Center, University of Maryland, College Park, MD 20742.

This paper deals with a class of image models based on random geometric processes. Theoretical and empirical results on properties of patterns generated using these models are summarized. These properties can be used as aids in fitting the models to images.

"Detecting Edges in Textures." Larry S. Davis, Department of Computer Science, University of Texas, Austin, TX 78712.

Some recent descriptive models for texture analysis are based on the spatial distribution of edges in the texture. Their success is thus closely linked with the reliability with which edges can be detected in textures. This paper discusses the detection of edges, using a simple class of edge detectors, in textures described by formal image models such as the Poisson model, occupancy model, etc. Experimental results are also reported.

"Statistical Models for the Image Restoration Problem."

B. R. Frieden, Optical Science Center, University of Arizona, Tucson, AZ 85721.

Over the past ten years progress has been made on the restoring problem by means of modeling the unknown optical objects $o(x)$ as a statistical entity. In radio astronomy, e.g., the object is the Fourier transform of the data, and so may be thought of as a power spectrum. Special methods exist for estimating power spectra, e.g. Burg's[1] maximum entropy (M.E.) approach, which supposes the best estimate to be the most random one and hence the one having maximum entropy, $\int dx \log o(x) = \text{maximum}$.

If the object is instead modeled as an unknown probability law on position for individual photons, other restoring methods arise, depending upon the norm adopted. For example, if the maximum-likelihood norm is used, this leads to a maximum entropy algorithm of the type[2] $-\int dx\, o(x) \log o(x) = \text{maximum}$ (compare with Burg's algorithm above).

These maximum entropy methods have the virtue of requiring the estimates $o(x)$ to obey a physical law, the second law of thermodynamics. This law after all represents a priori information about $o(x)$ and all a priori information ought to be injected into an estimate.

Some controversy existed until recently over which form of the maximum entropy law, Burg's above or Frieden's above, was the correct one to use on the basis of quantum optics. Kikuchi and Soffer[3] found, in fact, that in one limit Burg's is correct, and in another Frieden's is correct.

If further information is present about $o(x)$, alterations to the M.E. algorithm arise. For example, if it is know that $a \le o(x) \le b$, with a, b known, the maximum-likelihood norm leads to an algorithm[4]

$$-\int dx\,[o(x)-a]\,\log\,[o(x)-a] - \int dx[b-o(x)]\,\log\,[b-o(x)] = \text{maximum}.$$

Recently, we have sought an estimate of o(x) based on the principle of maximum Shannon information. Since o(x) and its image i(y) may be regarded as probability laws on positions x and y for a photon, the information throughput from object to image may be computed. We wondered what object o(x) would maximize this information throughput, over the class of objects that satisfy the image data as constraints. This new norm has led to some interesting results, and we shall compare restorations on this basis with corresponding ones using maximum entropy and least squares.

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"A Facet Model for Image Data." Robert M. Haralick, Department of Computer Science, Virginia Polytechnic Institute, Blacksburg, VA 24061.

(Abstract not available)

"Stochastic Image Models Generated by Random Tessellations of the Plane." J. W. Modestino, R. W. Fries* and A. L. Vickers, Electrical and Systems Engineering Department, Rensselaer Polytechnic Institude, Troy, NY 12181.

A useful class of two-dimensional random fields is described which can be generated by random tessellations of the plane. The random tessellations are in turn generated by marked point processes evolving according to a spatial parameter. Gray levels are assigned within elementary disjoint regions generated by the tessellations to have specified correlation properties with gray levels in contiguous regions. A complete second-order statistical description of the resulting class of random fields is provided. This includes not only autocorrelation function and power spectral densities but joint probability density functions. Several applications are discussed including the modeling of real-world imagery possessing inherent edge structure.

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*Current address: Pattern Analysis and Recognition Corp., Rome, NY.

"Image Segmentation as an Estimation Problem." T. Pavlidis and P. C. Chen, Department of Electrical Engineering and Computer Science, Princeton University, Princeton, NJ 08544.

Image segmentation is a process by which a picture is subdivided into regions of "uniform" properties.[1] In a number of cases one can assume that the picture is generated by a random process depending on a set of parameters A, with all the parameters having fixed values over (not necessarily connected) regions $R_1, R_2, \ldots R_n$. Then segmentation corresponds to the identification of $R_1, R_2, \ldots R_n$. In the simplest case we may assume that the brightness at each element follows a Gaussian distribution with mean m_i and variance $\sigma^2 (m_i >> \sigma^2$ for all i). The values $m_1, m_2, \ldots m_n$ and σ^2 are not known in advance, but n may be known. (For example n = 2 may correspond to subdividing a picture into dark and light regions.) A necessary step in the solution of this problem is to decide whether a given region R is contained entirely within one of the R_i's (i.e. it is "uniform") or not (i.e. it contains an "edge). In the simplest case this requires the testing of the hypothesis that the brightness values are generated by a Gaussian process with mean m and variance σ^2, where m and σ are not known in advance.

One possible strategy is to subdivide R into regions $P_1, P_2, \ldots P_k$, and estimate the values of the mean and variance over each one of them. If these values are close to each other, then it may be decided that R is uniform. There is a conflicting requirement regarding the choice of the size of R and $P_1, P_2, \ldots P_k$. The larger a region P_i is, the more reliable is the estimation of the mean but the more likely it is to intersect more than one of the regions R_i. The analysis of the statistics of the estimators determines a maximum size N_o of

the regions P_i. Then this process is performed over the whole picture. The result is a set of regions $S_1, S_2, \ldots S_r$ which are "uniform" and a region S where no decisions were possible. Also a set of the means $m_1, m_2, \ldots m_\ell (\ell \leq n)$ and an estimate of the variance σ^2 (or other statistics) are known. This enables a second pass over the picture where subsets of S are tested as to whether they have one of the means $m_1, m_2, \ldots m_\ell$. This allows the growth of the regions $S_1, S_2, \ldots S_r$ and the possible creation of new regions $S_{r+1}, \ldots S_q$. In general, there will still be a region S' where no decision can be made, and where most of the edges dividing regions would lie. It is suggested that edges be introduced by interpolation between the boundaries of the already found regions. The weakness of attempts to determine edges directly can be shown by a statistical analysis where one can estimate an inherent uncertainty in the location of the edges as a function of the difference in the parameters of generating process. For the simplest case this uncertainty is proportional to

$$\frac{m_i - m_j}{\sigma}$$

The detailed investigation of the simplest case as well as the case where all processes have the same mean but different variances is straightforward because of available results on estimators and the testing of hypotheses involving Gaussian processes. The results are now in the process of being extended to cases where the brightness at each picture element is not independent of the others, which is very important for segmentation by texture. A number of conclusions can already be drawn from this study.

(a) Direct edge detectors are inherently limited because they always use small regions. [1,2] Even when a careful choice

of the best edge estimate is made, the result is unreliable because of the smallness of the region. This offers a theoretical explanation of the practical observation that sophisticated edge detectors (e.g. Hueckel's [1,3]) do not give significantly better results than simpler ones.

(b) Region growing techniques or their generalizations (e.g. the split-and-merge algorithm [1,4,5]) should not insist on forcing a decision over all parts of the picture but instead should leave unlabeled regions. In the past this insistence has resulted in the generation of numerous "small regions" and the need for their subsequent elimination by heuristic techniques [1].

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"Image Models in Pattern Theory." Donald E. McClure, Division of Applied Mathematics, Brown University, Providence, RI 02912.

The pattern theory developed by Grenander provides a unified framework for the description of observed images in terms of algebraic and probabilistic processes that generate the images. The main elements of the general theory will be outlined and specific image models will be related to the general theory. Recent results on random fields, stemming from work stimulated by problems of image analysis, will be described within the context of pattern theory.

"Stochastic Boundary Estimation and Object Recognition." David B. Cooper, Division of Engineering, Brown University, Providence, RI 02912.

We will present a likelihood maximization formulation of object recognition and highly variable boundary estimation of object images corrupted by noise. Though some very general models will be considered, most of our details will be for underlying blob object and background images which are of constant but different gray levels. Blob boundaries are modeled as stochastic processes. We show how stochastic modelling and the use of cost functions realized as likelihood functions permit analytical quantitative investigation of many important matters such as boundary estimation error analysis, good computational schemes (sequential, parallel, etc.) for boundary estimation, and others. Some material will be presented on a stochastic treatment of texture and on fundamental considerations in the probabilistic modelling of scenes in general.

"Comparative Analysis of Line-Drawing Modelling Schemes."
Herbert Freeman, Department of Electrical and Systems Engineering, Rensselaer Polytechnic Institute, Troy, NY 12181.

The computer processing of line drawings necessarily requires that the line drawings be coded such that all nodes of the drawing, including those of all component segments, lie on a grid. The grid may be square, rectangular, logarithmic, or even curvilinear. The component segments may be straight or curved. For some coding schemes, such as the generalized chain code or the parallel-scan code, the grid is explicit; for others, such as the polygonal, spline, or Fourier series codes, it is implicit. The paper will critically examine the constraints imposed by the grid geometry and compare the various coding schemes in terms of ease of encoding, compactness of storage, precision, smoothness, facility for processing, and convenience for display.

"Syntactic Image Modelling Using Stochastic Tree Grammars."
K. S. Fu, School of Electrical Engineering, Purdue University, West Lafayette, IN 47907.

The basic concept of syntactic image modelling is introduced. Tree grammars and stochastic tree grammars are briefly reviewed. The use of stochastic tree grammars for image modelling, in particular texture modelling, is discussed. Preliminary results are presented.

"Differences between Attentive (Figure) and Preattentive (Ground) Perception." Bela Julesz, Bell Laboratories, Murray Hill, NJ 07974.

For almost two decades this author and his co-workers searched for texture pairs with identical second-order statistics (i.e., with identical autocorrelation functions, hence identical power spectra). In the great majority of cases such texture pairs could not be effortlessly discriminated (when briefly presented to prevent scrutiny), although the individual texture element duals are strongly discriminable. The latter corresponds to attentive (figure) perception where the phase (position) spectra are crucial, while in preattentive (texture) perception the phase (position) spectra usually are ignored. Recently, some examples were found for which iso-power-spectra texture pairs could be discriminated based on some local nonlinear features of collinearity, closure, connectivity, granularity, etc. These conspicuous features can be described by two "perceptual quarks": elongated blobs (e.g., bars and line segments) and their terminators. The preattentive texture system cannot evaluate position of these terminators, but can count their number.

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"Intrinsic Surface Characteristics: A Physically Motivated Alternative to Image Modeling." Jay M. Tenenbaum and Harry G. Barrow, SRI International, Menlo Park, CA 94025.

The interpretation of three-dimensional scenes requires an intermediate level of modeling that represents explicitly the orientation, reflectance, distance, and other intrinsic characteristics of the surface elements visible at every point in an image. Such physically-based features overcome the problems of variability and ambiguity associated with stochastic image features on which interpretation has conventionally been based. This paper briefly describes the advantages of intrinsic surface characteristics in a complete vision system and then examines the computational principles involved in recovering them from raw image data. The central problem in recovery is that information about all characteristics is confounded in the single brightness value available at each point in an image. Recovery thus depends on constraints derived from models of the scene, the illuminant, and the imaging process.

WORKSHOP ON IMAGE MODELING

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A Workshop on Image Modelling was held in Chicago, IL on August 6-7, 1979, under the joint sponsorship of NSF and the Office of Naval Research. Over 25 invited papers were presented on various aspects of statistical and structural image modelling. The Workshop proceedings will be published in book form in 1980.

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